EFFECT OF RADIATION ON TOPOPAH SPRING TUFF MECHANICAL PROPERTIES

Since radioactive waste may impose a radiation field on the rock that is exposed in the emplacement drifts and other excavations, we need to determine if radiation will alter the mechanical strength or other geomechanical properties of rock in the near-field of the proposed repository at Yucca Mountain in Nevada. We conducted a suite of uniaxial compressive tests to provide data on the effect of radiation on the compressive strength of Topopah Spring tuff, the rock type that forms the proposed repository horizon at Yucca Mountain.

We prepared 30 tuff samples as 2.5 cm x 7.6 cm right circular cylinders, and then exposed 15 of the samples to a 0.9 Grad dose of gamma radiation. Each of the irradiated samples had a corresponding control sample with similar distributions of cracks and vugs. We performed uniaxial compressive tests on all the samples, loading them to failure at a constant strain rate of 10^{-5} s^{-1}. We recorded the applied force and displacements and then determined peak strength and Young's modulus for all samples.

We found that the radiation had no significant effect on the tuff's mean peak strength for samples that experienced brittle failure, with mean peak strength of 185±49 MPa for irradiated samples and 169±24 MPa for control samples. But the few samples that failed along pre-existing subvertical cracks showed much lower mean peak strength for irradiated samples (about 70 MPa), suggesting that possibly the radiation weakened the cementing minerals in the cracks. We plan future tests on additional samples, to test a statistically significant number with well-characterized cracks. We also intend to use an inert gas in the sample holder during irradiation to remove complications due to humid air interacting with carbonates.

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Summary of the Effect of Radiation on

Topopah Spring Tuff Mechanical Properties

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We present results of a suite of uniaxial compressive tests conducted to provide laboratory data to determine how radiation affects the compressive strength of Topopah Spring tuff, which is the rock type for the proposed geologic repository at Yucca Mountain, in Nevada. We need to better understand what effect radiation has on the compressive strength of this rock because emplacement of radioactive waste may impose a radiation field on the rock that is exposed in the emplacement drifts and other excavations associated with the proposed repository. Thus, we must determine whether exposure to radiation will alter the mechanical strength or other geomechanical properties of rock in the very near-field region of the repository. Until now, data describing the effect of radiation on tuff from the potential repository horizon have been unavailable.

We made precise measurements of rock behavior in uniaxial compression on irradiated and non-irradiated samples of Topopah Spring tuff. Identical procedures were used for preparing and mechanical testing of all samples, except that some samples were exposed to gamma radiation. Results for the irradiated and non-irradiated samples were then compared. The results are in the form of stress-strain curves and tabulated strength and modulus values.

Samples for the experiments were prepared as right circular cylinders, 7.6 cm long and 2.5 cm in diameter. Unconfined compression tests were performed on 39 cylindrical core samples of tuff. Fifteen samples were subjected to a 9.5-MGy (0.9-Grad) dose of gamma irradiation from a ^{60}Co source over a 47-day period. The remaining samples were held as controls. Each sample was then loaded in uniaxial compression (at a constant strain rate of 10^{-5} s^{-1}) until it failed.

One statistical method for analyzing the effect of radiation is known as blocking. A block is a unit of sample material within which the variation of some attribute is less than its variation between blocks. Treatment comparisons are then made within blocks rather than across blocks. The different blocks can be viewed as independent replications of the comparison. The block size in our experiments is two, so the method is also known as the method of matched pairs. For each pair, one sample is exposed to a massive dose of gamma radiation, while the second sample acts as a control. Any radiation effect is detected by comparing the measured parameter between the members of a pair.

We determined mean values of peak strength and Young’s modulus for the cores in the 15 matched pairs used in the radiation study. The irradiated samples had a mean strength of 139 MPa ± 73 MPa, whereas control samples had a mean peak strength of approximately 154 MPa ± 36 MPa. The large amount of scatter in the values was expected and is generally attributed to the heterogeneity in the form of cracks and vugs present in the rock.

Stress-strain curves showed that most of the samples behaved in a linear elastic manner up to the point of brittle fracture, and that the Young’s modulus for matched cores was similar. Stress-strain curves for some samples showed nonlinear behavior at stress levels below the peak stress. For many of the pairs, the behavior for each of the samples was quite similar, but for some of the pairs, dissimilar behavior was observed for the two samples. To further evaluate this behavior, we divided the 15 pairs into two groups, termed the homogeneous and heterogeneous groups, based on stress-strain behavior for the pair. Nearly all of the samples in the homogeneous group failed by explosive brittle fracture. Both irradiated and non-irradiated samples in this group had a higher mean peak strength than that determined for the total dataset. Values for Young’s modulus for the irradiated and non-irradiated samples in the homogeneous group were identical, with similar standard deviations. For the homogeneous samples of welded tuff, radiation has little effect on the mechanical behavior in compression.

For the heterogeneous pairs, we found a significant difference between the mean peak strength observed for the irradiated and non-irradiated samples. The irradiated samples had a mean strength of approximately 70 MPa, and the non-irradiated had a mean strength of approximately 130 MPa. The values of Young’s modulus for the irradiated samples were also significantly lower than those for the non-irradiated samples, in this group of heterogeneous pairs. Preliminary examination of the core descriptions for these samples indicates that, for many of the pairs, both samples in the pair contained preexisting vertical or subvertical cracks. Also, for the irradiated samples, the failure occurred along one of these preexisting cracks. For the non-irradiated samples in this group, failure occurred more frequently by catastrophic or explosive fracture. A possible explanation of these results is that exposure to radiation weakened the carbonate cementing material in the cracks and fractures that were present in these samples.

One possible mechanism that could weaken a carbonate cementing material in a high radiation field is degradation of the carbonate by nitric acid formed by irradiation of moist air. This hypothesis could be evaluated by performing another similar set of experiments and changing the experimental procedure so that the irradiation vessel would be flooded with an inert gas such as argon instead of using air. A second possible mechanism is alteration of some of the hydrated minerals in the cementing material through radiolysis of the waters of crystallization. The alteration would weaken the cementing material and thus degrade the compressive strength.

In summary, we found that for homogeneous, uncracked samples of Topopah Spring tuff, exposure to gamma radiation had no discernible effect on the unconfined compressive (peak) strength or the Young’s modulus. However, results for samples that contained partially healed, preexisting vertical or subvertical cracks (the heterogeneous group) indicate that radiation may cause significant degradation of the strength and Young’s modulus. These results are preliminary, and additional studies are warranted to evaluate whether radiation does weaken cementing materials in welded tuff. However, if this is a real phenomenon, it has significant implications for the behavior of rock in the near-field region of the proposed nuclear waste repository.